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Publication Date

1966-02-01

UCRL-16711

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Berkeley, California

AEC Contract No. W-7405-eng-48

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February 1966

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Summary

Studies of low-yield nuclear reactions such as $(\text{He}^3, \text{He}^6)$ or $(\text{He}^4, \text{He}^8)$ require definite identification of about one interesting particle in the presence of 10^6 to 10^7 reaction product particles. Conventional ΔE -E identifier systems are of limited value in these experiments as a small fraction of the abundant reaction particles produce ΔE signals which deviate considerably from their normal value. The resulting false identification signals cause a general background in the identifier output spectrum which interferes with the peak due to interesting particles. In the improved identifier two ΔE detectors are employed; each time a particle passes through the counter telescope two identifications are made, each using one of the ΔE signals. If they do not agree with each other within prescribed limits (due to one of the ΔE signals deviating from normal) the event is completely rejected. Fast coincidence and pile-up rejector techniques are used to reduce the effects of chance coincidences between unrelated detector signals and a fourth counter is used to reject high energy particles which pass completely through the telescope.

Details of the instrument and its performance in several experiments are given, and the general problems in this type of work are also discussed.

Introduction

An important field of nuclear studies is concerned with measuring reactions produced in target nuclei bombarded by high-energy particles. Bombardment of a target (e.g., Mg^{26}) by α particles, for example, can cause many different reactions resulting in emission of different kinds of light particles (p, d, t, He^3 , He^4 , He^6 , He^8 , Li^6 , Li^7 , Li^8 , Li^9 , etc.) from the target, and the related production of many final nuclei (e.g., Mg^{24} , Mg^{22} , Na^{22} , etc.). Many experiments in this field require measurement of the energies and angular distribution of relatively populous reaction product particles. For example, this is true in inelastic scattering experiments designed to determine the energy level scheme of the target nucleus. Here, the probability of most competing reactions is small compared with that of elastic and inelastic scattering of the bombarding particle, and often no attempt need be made even to identify the type of particle. In order to study lower probability reactions, however, identification and selection of the desired particles becomes necessary. As the probability of the interesting reaction becomes smaller, the identification problem becomes greater owing to the fact that the detector system receives very large quantities of the more probable reaction products.

The work described here is directed toward this problem, and the results indicate the precautions necessary in this type of work. Most of the recent experimental work has been concerned with $(\text{He}^3, \text{He}^6)$ and $(\text{He}^4, \text{He}^8)$ reactions. As can be imagined, the probability of a 4-neutron transfer reaction is very small. In a reaction like $\text{Mg}^{26}(\text{He}^4, \text{He}^8)\text{Mg}^{22}$, about 10^7 undesired reaction product particles pass through the detector system for each He^8 particle. Despite this, our work¹ on this reaction has permitted the first determination of the mass of He^8 . The low probability of the reaction is best illustrated by noting that a total of only about 14 He^8 particles were observed in 60 hours using a cyclotron beam of $0.15 \mu\text{A}$ of 80 MeV α 's. The primary problem in this type of experiment is to remove unwanted background counts by every possible means.

Particle Identification Methods

Identification of a charged particle can be accomplished by measuring its total energy, and, at the same time, determining either the rate of energy loss of the particle in traversing the detector material or its time of flight across a known distance. If the charge on the particle is known, bending of the particle track in a magnetic field can also be used to provide identification. It is likely that the ultimate system for unique identification of very rare events will rely on a combination of these basic methods. However, the problems of measuring very short times and the size and mechanical problems associated with magnets, together with performance restrictions, make the technique of measuring energy-loss rate and total energy the most attractive single method for a wide range of particle types and energies. Improvements and extensions of this method for use in the particle energy range from approximately 10 to 200 MeV are the subject of this paper.

The energy-loss methods used for several years require a dual-detector system containing a transmission detector in which the particle deposits a small amount of total energy ΔE while the second detector absorbs the remaining particle energy E . The total energy of the particle is then easily calculated ($\Delta E + E = E_{\text{total}}$) and, by performing a more elaborate calculation based on a range-energy relationship, the particle type can be determined from the relative values of ΔE and E . As far as the actual experiment is concerned three philosophies are encountered. Some experimental groups favor storing each pair of ΔE - E signals on magnetic tape, then processing

the data on a computer at a later time. This is a slow process and the final information is not available during the course of the experiment. Other groups prefer to store the ΔE -E signal pair in an on-line computer which immediately computes the particle type, thereby permitting prompt display of the data. However, the calculation might well take 1 msec, which results in low data-handling rates. Furthermore, our experience indicates that computer time and memory space are too valuable to use for this purpose. We prefer to use a fast analogue calculation ($<5 \mu\text{sec}$) technique. However, when the identification system indicates a rare event, the signals the event produced in the detectors are stored in an on-line computer for a detailed examination of their validity. This feature eliminates certain chance coincidences and serves to give more confidence in the observation of very infrequent events.

Two types of calculation have been employed by different workers to determine the particle type from knowledge of the E and ΔE signals. The first method is based on a simplified Bethe's equation for the rate of energy loss. The second method, used originally by the present authors,² is based on the empirical relationship $R = AE^{1.73}$ where R is the particle range, E its energy and A is a constant for a particular type of particle. A discussion of the relative merits of the two methods is given in the authors' earlier paper² and recent experience has demonstrated the value of this method.

To introduce the new techniques it will be convenient to review the earlier identifier which used a dual-counter telescope. Figure 1 shows this instrument in block form. Signals from the detectors are amplified and fed to the identifier. A coincidence signal, which is obtained when a particle registers in both detectors, is used to start the timing sequence in the identifier. The key element in the identifier is a function generator producing an output signal proportional to the input signal raised to the power of 1.73*. This simulates the empirical range-energy relationship $R = AE^{1.73}$. By mixing the E signal with the ΔE signal (gated by a delayed gate waveform), the stepped waveforms shown in Fig. 1 are produced at the input and output of the function generator. In the short calculation given in Fig. 1, the quantity T/A depends upon the ΔE detector thickness T and also on the kind of particle (characterized by the parameter A). The sampler determines T/A by measuring the step on the top of the waveform at the output of the function generator.

This kind of identifier is quite adequate for studying nuclear reactions which have a reasonable cross section. This is illustrated in Fig. 2 which shows the amplitude distribution of identifier output pulses in a typical experiment. We

see very good separation of the various He and Li ions. By gating an analyzer on particles falling in the He^3 group, for example, the energy spectrum of He^3 particles can be observed, and, in this type of experiment, virtually no contamination is present in the spectrum due to leak-through of other types of particles.

Limitations of the Dual-Counter Identifier

The performance of the dual-counter identifier in low-yield reaction studies is not so impressive. Figures 3 and 4 show the identifier output spectrum and the energy distribution of He^6 particles produced in the reaction $\text{C}^{12}(\text{He}^3, \text{He}^6)\text{C}^9$. We see that the He^6 peak in the identifier output spectrum appears on the tail of the peak due to the very abundant He^4 particles. Consequently, the gate selecting He^6 particles permits a substantial number of α particles to pass through and the He^6 energy spectrum contains a large general background. Although the ground state He^6 peak for this reaction was distinguishable from background, other similar reactions produced no distinguishable peak.

A detailed examination of the processes which result in improper identification signals indicates that the following factors are involved:

(a) If a particle happens to pass along a major crystal plane in the ΔE detector, the energy deposited in this detector will be smaller than normal, and consequently the E signal will be larger than normal.

(b) When a particle travels through the crystal lattice in such a position and direction that it passes through a line of atoms (i.e., a line of much higher electron density than the average for the whole crystal), an excessive energy loss will occur in the ΔE detector. These effects, due to the crystal lattice in the ΔE detector, are called "channelling" and "blocking" respectively and, in either case, the identifier receives signals which depart considerably from their normal value. If the crystal direction is suitably oriented with respect to the particle beam these effects are negligible, but alignment to the degree necessary for very low cross-section work would be difficult experimentally.

(c) A statistical spread occurs in the signals produced in the ΔE detector, and this causes a "natural" spread in the identifier output pulses. Furthermore, occasional close range collisions of the particles with electrons in the detector can introduce a Landau tail in the energy distribution obtained from the ΔE detector. These excessive energy losses in the ΔE detector produce larger identifier output pulses than normal, and tend to cause high amplitude "tails" in the identifier output spectrum.

(d) The charge collection from a silicon detector can be a rather slow process and, partly for this reason and also to obtain good energy resolution in the measurement, the amplifier

* To accomplish this operation, the function generator takes the logarithm of the input signal, multiplies the result by 1.73, then takes the antilogarithm of this signal.

shaping networks usually have time-constants in the 1 μ sec range. In most of our experiments, a 0.4 μ sec single delay-line shaped pulse, integrated by a 0.1 μ sec R.C.time-constant is employed. This rather long measuring time results in a significant pile-up probability in the system. In our case the source of particles is a cyclotron which produces bursts of particles of about 10 nsec duration at a repetition rate of 10 Mcs. Therefore, all events arising in five beam bursts occur within the resolving time of the amplitude-measuring part of the apparatus. This case is too complex to treat here, however, there is a distinct likelihood that the chance occurrence of two of the abundant particle (within the resolving-time) can produce an identifier output which is indistinguishable from that produced by the rare event of interest. In the (He^4 , He^8) type of experiment, the chance coincidence of a deuteron and α particle, each in a certain energy range, identifies as He^8 . If we are to trust the identification we must clearly reduce chance coincidences to a minimum. Even then, a correlation may exist in the emission of the deuteron and α particle (i.e., they may occasionally be produced in pairs during nuclear break-up), and the only way to compensate for these events in the final experimental analysis is to make a reasonable estimate of their probability.

The Triple-Counter Identifier

The most important limitation is spread in the energy absorption in the ΔE detector. Whatever mechanism causes a particular ΔE pulse to depart from its normal value, we can assume that its probability is small if the departure is large. If a method can be devised to reject all events in which the ΔE signal is considerably larger or smaller than normal for that particular energy and type of particle, most of the poor identifications can be eliminated while losing only a very small fraction of the total events. This result is accomplished by using an additional ΔE detector, and making two identifications to permit comparison of the two results for validity. If the two identifications differ by a significant amount, the event is rejected. As there is only a very small chance of both ΔE signals for a particular event departing from normal in the same direction by about the same amount, very few poor identifications result after the rejection process.

Figure 5 will be used to describe the operation of the new identifier. The detector telescope will, for the moment, be considered to consist of three detectors called ΔE_2 , ΔE_1 and E in the order encountered by the particle. Usually the ΔE_2 and ΔE_1 detectors will be of nearly the same size with the ΔE_2 detector being slightly the larger of the two. The E detector will usually be thicker than either ΔE . Signals from the detectors are amplified, various coincidence and other requirements are applied, and if these are met, the signals appear at the input to the identifier. A timing pulse produced from the ΔE detector signals, and a master pulse generated only if the two ΔE signals are followed by

the E signal in a prescribed short time interval, also feed the identifier. The timing sequence in the identifier starts on arrival of the timing pulse but all circuits are reset in 0.5 μ sec if no master pulse is received. Thus, a reasonable spread in the rise-time of thick E detectors does not affect the timing operations in the identifier. Assuming that all the foregoing conditions are met, the identifier waveforms are as shown in Fig. 5.

The three signals are mixed in a similar manner to the two signals of Fig. 1. First the ΔE_1 signal is added to the E signal (about 1.5 μ sec after the timing pulse) and, a short time later, the ΔE_2 signal is added to ($\Delta E_1 + E$). The resulting waveform feeds a function generator having the transfer function: $\text{Output} = (\text{Input})^{1.73}$. A sampler unit (No.1) then samples the two steps on the function generator output waveform, while another sampler (No.2) samples the sum of the two steps. The normal size of the first pulse appearing on the output of sampler No.1 is proportional to T_1/A and the second pulse is proportional to T_2/A where T_1 , T_2 are the ΔE_1 and ΔE_2 detector thicknesses, respectively, and A is a constant for a given type of particle.

The Pulse Ratio Calculator calculates the ratio of the two pulse heights from sampler No.1 and its output is proportioned to $\log KT_2/T_1$, where K is a constant which can be adjusted to give the same standard output in all experiments, even though the ratio of ΔE detector thicknesses may differ. Note that all events in which the energy absorption in the detectors is normal will produce the same signal at the output of the ratio calculator independent of their type and energy. This result depends only on the assumption that the range-energy relationship for all particles of interest has the form $\text{Range} = AE^{1.73}$. The signal spread due to statistics, Landau effect, channelling and blocking in the ΔE detector signals is reflected in a spread in the output pulse from the ratio calculator. If an abnormally large (or small) pulse occurs in one of the ΔE signals a resulting large departure of the output of the ratio calculator from its normal value occurs. A single-channel analyzer whose passband is centered on the normal output of the ratio calculator and whose window is adjustable, picks out only those pulses in which the ratio calculation gives a reasonably normal answer. The control which adjusts the window of the single-channel analyzer is calibrated directly in terms of the percentage error in the calculated value of T_2/T_1 .

The single-channel analyzer output is used to open a rejector gate through which the output of sampler No.2 (delayed by 1 μ sec) is fed. The identifier output therefore consists of pulses whose height is characteristic of particles which lose "normal" energy in each detector. The identifier pulses feed a router which is adjusted to route an analyzer into different storage groups according to the type of particle. When the router accepts a pulse, it opens a signal gate in the identifier to allow the total signal (i.e., $\Delta E_1 + \Delta E_2 + E$) to pass to the analyzer (via a biased amplifier and stretcher).

The purpose of the triple-counter identifier is primarily to remove events in which one of the ΔE signals departs by a significant amount from its normal value. This removes events in which channelling or Landau effects occur to any significant extent. It also incidentally removes a substantial fraction of those events in which pile-up signals occur but more definite measures must be used to eliminate pile-up effects in our type of experiment. These measures will be described in the following section.

The Complete System

Figure 6 shows the complete system used in a recent experiment and Fig. 7 shows timing of the waveforms in the system. The ΔE_2 , ΔE_1 , and E detectors feed preamplifiers having a fast rise-time (<10 nsec). Preamplifier output signals travel through about 150 feet of 125 Ω cable from the target room to the counting area where the remainder of the equipment is located. Here the signals split to feed both a pile-up rejector unit and linear amplifiers. The signals into the pile-up rejector are differentiated to produce 20 nsec wide pulses, and, when coincident pulses occur on the three input lines to the rejector, an inspection period of about 800 nsec is started. If no further signals occur during the inspection period, the validity (i.e., no pile-up) of the event is indicated by a valid event signal. If any pile-up occurs the lack of a valid event signal prevents processing of the event by the remainder of the system. When the identifier is busy processing a signal, an inhibit waveform, generated by the identifier, prevents acceptance of further input pulses by inhibiting the fast coincidence circuit in the pile-up rejector. We also note that the pile-up rejector is activated whenever a signal appears on one or more of its three input lines and, if a coincident signal (i.e., on all three lines) occurs within 800 nsec, the event corresponding to the coincidence is completely rejected.

The linear signals are amplified and delay-line shaped. The base-line crossover time of the double delay-line signals is picked off, and fast coincidences are taken between the valid event signal and the three crossover signals. (If the E detector happens to be quite thick with consequent slow collection, the requirement for its connection to the pile-up rejector, and to the amplifier fast coincidence circuits, can be removed.) The timing signals actually used for fast coincidence purposes are outputs from single-channel analyzers in the amplifiers occurring at the same time as the crossover signals so that energy windows can be set on all the detector signals. When all fast coincidence requirements are met a pulse is fed into the master-gate generator.

In the type of experiment for which this equipment is designed, it is usually possible to arrange the detector thicknesses so that the particles of interest stop in the E detector and a large fraction of the unwanted particles (e.g., elastically-scattered beam particles) pass through the E detector. We use a fourth detector (E_{REJ})

to detect these particles, and its output, after suitable amplification, provides an inhibit waveform for the master-gate generator. All linear signals pass to the identifier through gates controlled by the master-gate generator. When the system is correctly set up, the only signals allowed into the identifier are those which produce signals only in the ΔE_2 , ΔE_1 , and E detectors, for which virtually no pile-up effects are present, and for which each of the detector signals is in a pre-calculated energy range.

The operation of the identifier and router were described briefly in the previous section and certain features will be dealt with later. The remaining component in Fig. 6 is, in many ways, the most important. The 4-channel pulse generator, which actuates transistor chopper circuits in the preamplifiers, is used for testing and setup of the system prior to an experiment. To facilitate this, the system is calibrated so that the pulser dials read directly from zero to 100 MeV (to better than ± 100 keV). Computer programs are available for range-energy calculations and these are used to calculate energy losses in the detectors for the range of interesting particles. Prior to any experiment, pulser-simulated events are used to check the complete apparatus.

It is important to realize that the setup of a complex instrument in which a rather elaborate analogue calculation is necessary, demands special care and precautions. Moreover, it is obvious that empirical adjustments during the course of an experiment are out of the question. The most important adjustment in the identifier itself is that associated with the power-law relationship. Fortunately the circuit design of the function generator has proved stable, so that the initial adjustment for the 1.73 power-law, carried out during production of the first instrument, has required no change in two years of use. Initial adjustment was accomplished by making accurate electrical measurements of the law of the function generator unit. A second unit, made recently, seems to behave in a similar manner. Another important parameter, which must be adjusted prior to each experiment, is the equality of gain of the complete amplification chains associated with the ΔE_2 , ΔE_1 , and E detectors. The required gain depends on the energy of the particles of interest in the particular experiment. The accurate-amplitude 4-channel pulser is used for this adjustment and facilities are included in the system for rapid adjustment of gains to an equality of about $\pm 0.1\%$. The stability of the whole system during a 5-day experiment appears to be better than $\pm 0.25\%$. Pedestals in all signal gates must be very small since the operation of the identifier depends upon the direct proportionality of signals to the energy release in the detector. The gates used here allow the pedestals to be adjusted to zero initially and long-term stability is better than ± 10 mV.

In recent experiments, the results of which will be described later, the number of desired events was very small. In these circumstances, each event assumes rather large importance and direct confirmation of the identification is

desirable. For this reason, the system has been extended to include a multiplexer, which, when the identifier indicates a desired event, stores the ΔE_2 , ΔE_1 , E_{Total} (i.e., $E + \Delta E_1 + \Delta E_2$) and the identifier output pulse. It then presents each of these signals in rapid succession (about every 25 μsec) to a 4096-channel analogue-to-digital converter which is attached to a PDP-5 computer. The computer immediately types out the amplitudes of the four signals. The computer also automatically checks the whole system at 12-minute intervals. To do this, it triggers the 4-channel pulser to produce a set of signals corresponding to one of the desired particles at the inputs to the preamplifiers. These signals are processed in the same way as a real event and the computer types out the amplitudes of the four output signals together with the notation "calibration."

System Details

The primary purpose of this paper is to describe the method and results. Complete information on the instruments can be found by consulting reference No.4. However, we will discuss a few of the more interesting details here.

(a) Four-Channel Pulser

In most experiments using accelerators, the complex counting and measuring instruments must be located remotely from the target room. Preamplifiers, on the other hand, must be located near the detectors which are close to the target. To simulate detector signals the usual practice is to use a charge-sensitive preamplifier configuration, and to feed a step-function through a very small capacitor to the input of the preamplifier. If the calibration of such a system is to be checked accurately using a pulser, the step function amplitude must be accurately defined. Unfortunately, a conventional pulser located in the counting room does not meet this requirement owing to the unknown (and variable) resistance of the cable from the counting to target room (we assume that the cable is correctly terminated).

To avoid this problem we use the pulser shown in Fig. 8. Here a transistor chopper, containing transistors Q1 and Q2, is built into a small head unit which attaches directly to the test input of the preamplifier. The coaxial cable linking this chopper unit to the main unit carries both the dc reference voltage, which is chopped by the transistors, and also the pulse required to switch transistors Q1, Q2 into conduction for a short time. The dc reference voltage is variable from zero to 10 V and a 10:1 capacitance attenuator at the output of the chopper results in a 1 V maximum step into the preamplifier test capacitor. This voltage, fed into a 4.34 pF test capacitor, corresponds to 100 MeV absorbed in a silicon detector. The helical potentiometer dial on the pulser unit therefore reads directly in MeV. The variable capacitor in the chopper allows precise adjustment of the output voltages of all choppers to the correct value, and the balance adjustment is used to reduce the chopper pedestal to a minimum.

(b) Fast Preamplifier

In many respects this unit, shown in Fig. 9, is similar to conventional preamplifiers. However, the use of a high-mutual conductance field-effect transistor results in improved behaviour with regard to rise-time and energy resolution for large detector capacitances. This is very important in this application as the pile-up rejector requires fast pulses for ideal operation and, also, the thin ΔE detectors used with this instrument necessarily introduce rather large capacitances. Table 1 summarizes the performance of the preamplifier. The criterion of good performance in this application is not the same as in the F.E.T. preamplifiers used in high-resolution γ -ray spectroscopy.

Table 1: Performance of Fast Preamplifiers

Capacity	0	20 pF	100 pF	250 pF
Rise-Time (10-90%) nsec	9	10	12	15
Energy Resolution (keV, Si FWHM)	5.5	6.5	11.5	22

Effective variation of the test and feedback capacitors is achieved, as shown in Fig. 9, by adjustable piston-type trimming capacitors having one side grounded. The feedback capacitors in the preamplifiers are all adjusted to give the same overall gain, and the test capacitors are matched to a standard capacitor. The fact that one side of the trimming capacitors is grounded simplifies this adjustment. Moreover, the piston capacitors are sealed at the end opposite to the adjustment screw, so the whole unit can be potted in silicone resin while retaining the ability to adjust the capacitors.

(c) Pile-Up Rejector Control Circuit

The function of the pile-up rejector unit has been described earlier, and Fig. 10 shows the logical arrangement of the control circuit of this unit. The control unit consists, essentially, of two one-shots (0.8 μsec and 1.2 μsec) in sequence, and a control flip-flop. The condition of the flip-flop at the end of the 0.8 μsec inspection period, defined by the first one-shot, determines whether a "valid-event" signal will be generated. The fast coincidence circuit, which sets the control flip-flop, is inhibited during the 0.8 μsec and 1.2 μsec periods defined by the one-shots and also when an "identifier-busy" signal is received from the identifier. The control flip-flop is reset by the appearance of a signal in any of the three input lines. If the signal happens to be one of a coincident set accepted by the fast coincidence circuit, the "set" input to the control flip-flop overrides the "reset" input.

A "valid event" signal occurs only if a coincident signal is accepted by the fast coincidence circuit, and if no signal occurs on a signal line in the next 800 nsec period. This prohibits acceptance of any pile-up pulses by the whole system.

(d) Ratio Calculator (Comparator)

Most of the circuits used in the triple-counter identifier are the same as those used in the dual-counter identifier described in Ref. 2. However, the ratio calculator has no counterpart in the dual-counter identifier.

Figure 11 shows the calculator in block form. The input signal from sampler No. 1 feeds a logarithmic circuit and the output from this circuit is amplified by a factor of about 80. At an intermediate point in this amplifier, a pedestal is added to the second pulse by turning on current in Q1. The difference in amplitude between the two pulses at the output of the amplifier is given by:

$$\theta = \log \frac{KT_2}{T_1}$$

where K is determined by the pedestal introduced by Q1. A sampler circuit clamps the top of the first pulse to ground level so the positive excursion on the second pulse is a direct measure of θ . The single-channel analyzer then selects only those events in which the value of θ falls in a prescribed range.

Experimental Results

Development of a new technique usually results in experiments which task it to the limit. Our case is no exception to this rule. The good separation of He, Li, and Be ions in a difficult case is illustrated in Fig. 12. The behaviour in the $^{12}\text{C}(\text{He}^3, \text{He}^6)\text{C}^9$ reaction, which represented about the limit of applicability of the dual-counter identifier (see Figs. 3 and 4 for comparison), is shown in the energy spectrum given in Fig. 13 for a run with the new identifier. The spectrum is seen to be largely free of unwanted background counts.

These observations led to the proposal to study $(\text{He}^4, \text{He}^8)$ reactions, first to determine the mass of He^8 , then to use this reaction to study the edge of stability against particle emission for neutron deficient isotopes of the light elements. While early experiments in the summer of 1965, using the triple-counter identifier, indicated the observation of He^8 in the identifier spectrum, the energy spectrum of the selected events was contaminated with background counts which prevented accurate determination of the mass of He^8 . We then recognized that random coincidences of more common particles, occurring during the resolving time of the system, might cause false identification pulses which could be confused with the He^8 . This resulted in the design of the pile-up rejector system which further improved the background rejection and made possible definitive determinations¹ of the mass of He^8 .

The identifier spectrum shown in Fig. 14 was obtained in a recent $\text{Mg}^{26}(\text{He}^4, \text{He}^8)\text{Mg}^{22}$ experiment with 80 MeV α particles. A comparison between the top of the He^4 identifier peak ($\sim 4 \times 10^5$ counts) with the few He^8 particles is misleading,

since about 99% of all α 's passing through the detector system are rejected by the E_{REF} detector and by energy window settings in the amplifiers. We also note that the energy windows were deliberately opened in this experiment to allow Li^6 particles through for calibration purposes. This allowed very low energy Li^6 ions into the system to which the low amplitude tail on the Li^6 peak in the identifier spectrum can be attributed. The dotted line shows the performance in an earlier experiment when the Li^6 (and consequently these Li^6 ions) was removed by energy-window settings in the amplifiers. The expected positions of peaks due to chance coincidences are also shown in Fig. 14.

For the purpose of this experiment, the pulse-height analyzer viewing the energy spectrum was gated by a single-channel analyzer with its lower and upper levels set to A and B respectively in Fig. 14. The resulting energy spectrum for counts appearing only in the " He^8 " identifier peak is shown in Fig. 15, each count being represented by a box one count high and 250 keV wide. This spectrum was plotted from data typed out by the computer immediately after the appearance of each count. The shaded boxes represent counts which can be rejected as chance coincidences between deuterons and α particles. A later paper will describe the procedure used for rejecting these counts. We see that most of the remaining eighteen counts fall in two peaks corresponding to the ground state and first excited state of Mg^{22} . The measured mass excess of He^8 is 31.65 ± 0.12 MeV which agrees well with a theoretical prediction.

The identifier has also been used for studies² of long-range particle emission in spontaneous fission of Cf^{252} . About 500 He^8 particles have been observed as the third fragment during the course of this experiment (~ 1 in 10^6 fissions).

Acknowledgments

Many of our co-workers have made contributions to this work. Bob Lothrop, Morris Roach, and Harry Smith supplied the detectors used in experiments, while Stuart Wright constructed nearly all the equipment and carried out most of the calibration and check-out. Several graduate students performed the boring, but necessary, task of watching over the system during the long nights of waiting for infrequent events. Claude Détraz took part in the early experiments and Gil Butler was a notable contributor to all phases of the experiments. Sam Cosper, a relative latecomer to the work, has contributed much to the interpretation of background counts. Finally, the operating staff of the 88" cyclotron must be thanked for providing a reasonably constant beam of particles of the required energy during very long experiments.

References

*This work formed part of the program of the Nuclear Chemistry Division of the Lawrence Radiation Laboratory and was supported by AEC Contract No. W-7405-eng-48.

1. J. Cerny, S. W. Cospers, G. W. Butler, R. H. Pehl, F. S. Goulding, D. A. Landis, and C. Détraz, UCRL-16705 (Feb. 1966) to be published in Phys. Rev. Letters March, 1966.
2. F. S. Goulding, D. A. Landis, J. Cerny, and R. H. Pehl, Nucl. Inst. and Methods 31, 1 (1964).
3. C. Erginsoy, H. E. Wegner, and W. M. Gibson, Phys. Rev. Letters 13, 530 (1964).
4. Drawings of the instruments can be obtained by writing the Lawrence Radiation Laboratory Technical Information Division, Berkeley. The drawing numbers are: Three Counter Particle identifier 11x366lp-1, Pile-up rejector 11x456lp-1, Four channel pulser 11x308lp-1, Four channel router 11x237lp-1 and Fast field effect preamp. 11x483lp-1.
5. S. W. Cospers, J. Cerny, and R. Gatti, (in preparation).

Figure Captions

Fig. 1. Dual-counter identifier block diagram.

Fig. 2. Dual-counter identifier spectrum for high-yield reaction.

Fig. 3. Dual-counter identifier spectrum for low-yield reaction (He^3 on C^{12}).

Fig. 4. Energy spectrum of He^6 ions for case of Fig. 3.

Fig. 5. Block diagram of triple-counter identifier.

Fig. 6. Block diagram of system associated with triple-counter identifier.

Fig. 7. Timing of waveforms in system.

- 1) Input signals from amplifiers.
- 2) $E, \Delta E_1, \Delta E_2$ crossover output (delayed by controlled amount) from amplifiers. This becomes the timing pulse to identifier.
- 3) E_{REJ} inhibit waveform.
- 4) Delayed signal from amplifier into linear gate (in amplifier).
- 5) Inspect period for pile-up rejector. If a second event occurs in this time it prevents waveform.
- 6) Valid event signal.
- 7) Master gate. This gates all signals and feeds the identifier too.
- 8) Stretched signals from amplifiers to identifier.
- 9) Summed signal in identifier ($E + \Delta E_1 + \Delta E_2$).
- 10) Sampler 1 output.
- 11) Sampler 2 output.
- 12) Ratio calculator output pulse.
- 13) Strobe to router.
- 14) Delayed signal to identifier linear gate (internal to unit).
- 15) Output signal from identifier to analyzer.

Fig. 8. Block diagram of test pulser.

Fig. 9. Schematic of fast preamplifier.

Fig. 10. Block diagram of pile-up rejector.

Fig. 11. Schematic of the ratio calculator in identifier.

Fig. 12. Performance of the identifier for $\text{C}^{12} + \alpha$ reaction.

Fig. 13. Energy spectrum of C^{12} (the He^3, He^6) C^9 reaction (compare with Fig. 4).

Fig. 14. Triple-counter identifier output spectrum in a low-yield reaction
(80 MeV α 's on Mg^{26}).

Fig. 15. Energy spectrum of He^8 events from the reaction $\text{Mg}^{26} (\text{He}^4, \text{He}^8) \text{Mg}^{22}$.

MUB-9653

Fig. 1

MUB-4285

Fig. 2

MUB-9628

Fig. 3

MUB-4506

Fig. 4

MUB-9660

Fig. 5

MUB-9659

Fig. 6

MUB-9656

Fig. 7

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Fig. 8

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Fig. 9

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Fig. 10

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Fig. 11

MUB-6842

Fig. 12

Fig. 13

MUB-9483

Fig. 14

MUB-9629

Fig. 15

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